

S/3-32

P-14

193065

Ka-Band Study—1988

J. W. Layland
TDA Planning Office

R. L. Horttor
Telecommunications Systems Section

R. C. Clauss and J. H. Wilcher
TDA Technology Development Office

R. J. Wallace
TDA Engineering Office

D. J. Mudgway
TDA Mission Support and DSN Operations Office

The Ka-band study team was chartered in late 1987 to bring together all the planning elements for establishing 32 GHz (Ka-band) as the primary downlink frequency for deep-space operation, and to provide a stable baseline from which to pursue that development. This article summarizes the results of that study at its conclusion in mid-1988, and corresponds to material presented to NASA's Office of Space Operations on July 14, 1988. For a variety of reasons, Ka-band is the "right" next major step in deep-space communications. It offers increases in the downlink telemetry capability on the order of 6 to 10 dB. It offers improved radio metric accuracy through reduced plasma sensitivity and increased bandwidth. Because of these improvements, it offers the opportunity to reduce costs in the flight radio system or in the DSN by allocating part of the overall benefits of Ka-band to this cost reduction. A mission scenario is being planned that can drive at least two and possibly all three of the DSN subnets to provide a Ka-band downlink capability by the turn of the century. The implementation scenario devised by the study team is believed to be feasible within reasonable resource expectations, and capable of providing the needed upgrade as a natural follow-on to the technology development which is already underway.

I. Introduction

The Ka-band study team was chartered in late 1987 to bring together all the planning elements for establishing 32 GHz (Ka-band) as the primary downlink frequency for deep-space operation, and to provide a stable baseline from which to pursue that development. A working premise for the study was that the DSN should have full Ka-band downlink services available on the 70-meter and both 34-meter subnets by the

year 2000. That premise was examined during the study and found to be consistent with an optimistic view of potential flight missions, and found to be achievable under resource assumptions consistent with that mission scenario.

The work of the study coalesced on schedule as a top-level plan for establishing Ka-band in the DSN. It was presented, after suitable JPL review, to NASA's Office of Space Opera-

tions on July 14, 1988. The final report¹ documents the study results and plan as of the date of that presentation. The report spans the full range of the study effort, from technology development to operations considerations, and from mission requirements to selection rationale for various potential implementation scenarios. This article is a subset of the material to be found in the study's final report, providing a brief summary which emphasizes the nearer-term aspects of the planning for evolution to Ka-band. Readers interested in greater depth should refer to the final report and thence to the many references catalogued there.

Advantages of the higher frequency accrue to both telemetry and radio metric services. For telemetry, there is an anticipated increase in channel capability of 4 to 10 times due to the better directing of energy for assumed fixed sizes of antenna. This is mitigated somewhat by the uncertainties that exist today in weather-induced attenuation and system noise, and in component efficiencies. These uncertainties drive much of the technology development work discussed later in this article.

For radio metrics, the higher frequency means less sensitivity to plasma-induced errors, and hence higher precision for both navigation and many radio science measurements. In addition, the wider allocated bandwidth of 500 MHz could be used to support more accurate delay/range measurements. On the flight mission side, some of these benefits can be traded for reductions in antenna size or transmitter power, facilitating the construction of some very constrained mission elements such as a Mars rover.

A baseline plan for the evolution to higher frequencies exists in broad form and is documented in the current DSN Long-Range Plan and the 1987 Construction of Facilities Plan. The technology base upon which to build has been documented in part in the special Ka-band issue of the *TDA Progress Report* [1], and in a plethora of other scattered reference material. These elements formed the background against which to pursue the team's planning activities and with which to focus the necessary analysis.

II. Network Performance and Mission Benefits

The performance of the 70-meter antenna at Ka-band was predicted prior to its construction, as shown in Fig. 1.² Measurements

of the actual 70-meter Ka-band performance baseline are yet to be done. Technology work needed to achieve the higher levels of performance form a part of technology development planning to be discussed later in this article. The predicted Ka-band performance of the 34-meter antenna is shown in Fig. 2. This performance was based on analytical work done in May 1988 by D. Bathker.³

The value of Ka-band to a specific mission depends upon several variables in addition to ground antenna gain. These include receiver noise temperature, atmospheric attenuation and noise temperature, pointing accuracy, downlink power, etc. Atmospheric effects depend upon the randomly varying weather as well as viewing geometry. Link performance is thus dependent upon the spacecraft position in the sky. Figure 3 is a typical telecom prediction curve for the data rate achievable at 90 percent confidence from a spacecraft at equatorial declination, using either Ka-band or X-band, with 21 watts RF power and a Voyager-size 3.66-meter antenna.⁴ These curves are based upon current best understanding of the weather model⁵ and Ka-band device behavior, coupled with the optimized Ka-band performance depicted in Fig. 1.

The proposed Cassini mission consists of a Saturn orbiter carrying a probe for the atmosphere of the satellite Titan. In a very real sense it is a Galileo mission at Saturn instead of Jupiter and, hence, at significantly greater distance from Earth. The decrease in signal strength due to this greater distance could be comfortably compensated for by switching the downlink from X-band to Ka-band, thus making Cassini one of the several candidates for DSN Ka-band services.

Early in 1988, the Cassini preproject teams concluded a Science Data Return Study⁶ which analyzed in detail a number of possible downlink options. They observed that a Ka-band 3-watt downlink could return all the expected baseline science instrument data, but was not yet technologically mature enough to be selected as the primary downlink. Other improvements to the downlink performance, such as the new long constraint length convolutional code to be flown experimentally on Galileo [2] or improvements to the DSN X-band receiving performance (to be discussed later in this article), could also satisfy the data transfer needs as long as the science data load does not grow above currently estimated levels.

³D. Bathker, private communication.

⁴Horttor, op. cit., pp. 15-30.

⁵Ibid., pp. 60-65.

⁶D. Collins et al., "Cassini Science Data Return Study," presentation viewgraphs (internal document), Jet Propulsion Laboratory, Pasadena, California, January 1988.

¹J. W. Layland et al., *Ka-Band Study-1988, Final Report*, JPL Publication D-6015, Project Document 890-212 (internal document), Jet Propulsion Laboratory, Pasadena, California, January 15, 1989.

²R. L. Horttor, editor, *Ka-Band Deep Space Communications*, JPL Publication D-4356 (internal document), Jet Propulsion Laboratory, Pasadena, California, p. 26, May 15, 1987.

The Mars Rover Sample Return mission is another candidate future mission that could benefit significantly from the adoption of Ka-band as its primary downlink frequency. The added link performance enables use of higher data rates, allowing wider travel by the rover supported by the rapid communication of guidance information from Earth. Part of the Ka-band advantage can simultaneously be allocated to enable use of a smaller rover antenna size that is lighter in weight and fits conveniently into the carrier vehicle. It also enables routine support from the 34-meter DSN antennas instead of competing for more limited 70-meter antenna time.

A third candidate mission that would benefit from Ka-band is the Solar Probe, which will approach within four solar radii of the Sun's surface to perform its scientific measurements. X-band communications can provide neither an adequate science telemetry return through the solar corona nor Doppler accuracy to 0.1 mm/sec for the gravity field measurement. A two-way Ka-band link together with X-band as a calibration signal appears to be the best way to achieve the accuracies that are required to meet the celestial mechanics objectives for the mission.

III. Main Building Blocks and Options

It is apparent that there are mission scenarios for which any or all of the DSN subnets will be required to be Ka-band-capable by the end of this century. Each of the three current (1988) DSN subnets has been examined to determine its potential at Ka-band and to define the principal configuration options for each. On the old 34-meter "standard" subnet, the structure and surface quality are totally inadequate for use at the 32-GHz Ka-band frequency. Replacement of the 34-meter standard antenna appears to be the only realistic option for providing any of several added capabilities, including Ka-band, on this subnet. By way of contrast, the much newer 34-meter "high-efficiency" (HEF) subnet is thought to have adequate structural stiffness and surface quality to provide reasonable Ka-band efficiency. The microwave feed area, however, is essentially filled with equipment providing current services, and needs to be totally reconfigured to make room for any new services. A similar story holds for the newly enlarged 70-meter antenna, in that a reasonable level of Ka-band performance should be attainable without significant structural changes. A rigorous program of antenna calibration will be required to attain the expected peak level of performance from the large antennas. This calibration will provide improved beam pointing and automatic compensation for surface distortion and beam deflection due to gravity, thermal effects, and wind load.

Consideration of Ka-band in the DSN cannot stand alone, because most of the present frequency capabilities need to be

retained for the foreseeable future. Support of the Pioneers using S-band uplinks/downlinks will continue as long as these spacecraft remain functional. Support of the Voyagers using S-band uplinks/SX-band downlinks will also continue well into the next century while these spacecraft cruise through previously unexplored regions of the outer solar system. With its delayed launch, the Galileo prime mission has been deferred into the latter half of the 1990s and could easily operate past the turn of the century. Galileo requires X-band downlink performance at least equal to the best available today, and responds to an S-band or X-band uplink. Table 1 summarizes the current, forecast, and other known potential frequency-band support requirements on the DSN for the next decade. Essentially all current capabilities will need to be retained at a technical performance level equal to or better than current performance while the addition of Ka-band is made to support the new missions.

The option menu for potential configuration changes to the three deep-space subnets of the DSN is catalogued in Table 2. Conceptual design for each of these was carried out with support from the Ground Antenna and Facilities Engineering Section and the Radio Frequency and Microwave Subsystems Section. A discussion of the entire option set appears in the final report.⁷ Only a selected subset appears in this article. Configuration drawings for the antenna mechanical elements described here were provided by the Ground Antenna and Facilities Engineering Section.⁸ While much has been learned in the examination of these options, there is still much to be learned about the process of designing for Ka-band and beam waveguide. Experience gained through the design and installation of the new advanced development antenna at DSS-13 should provide that knowledge.

Replacement of the 34-meter standard antenna is driven by several needs: Ka-band downlink for deep space use, X-band uplink with SX-band downlinks, Ku-band for support of the proposed Quasat mission or others in the class of Earth-orbiting interferometry terminals, and C-band for potential cooperative support to Soviet missions. Still another need is for continued reliable support (and modest performance improvement) at the existing S- and X-band channels. These older antennas were built in the early 1960s as 26-meter antennas, and are simply nearing the end of their productive lives. Two replacement options were considered to enable installation of Ka-band capability: an HEF antenna like DSS-15 with all microwave equipment mounted in a cone structure in the antenna dish,

⁷Layland et al., op. cit.

⁸R. Van Hek et al., *Ka-Band Study Plan for the Antenna Mechanical Hardware* (internal report), Ground Antenna and Facilities Engineering Section, Jet Propulsion Laboratory, Pasadena, California, April 1988.

and a centerline beam waveguide antenna like the new DSS-13 with the feeds and related equipment in a nonmoving area in the pedestal (Fig. 4). Of the two, the HEF-type antenna is more completely understood by those who will ultimately have to do the implementation, while the beam waveguide design appears to offer the best flexibility and opportunity for growth to meet future needs.

In addition to providing space for future growth, the non-moving aspect of the equipment area of the beam waveguide antenna enables technical performance improvement for X-band as well as Ka-band. Because it does not have to tilt, the cryogenic cooler for the low-noise traveling-wave maser amplifier can be made to operate at below atmospheric pressure, permitting a device temperature of around 1.5 kelvins (versus 4.5 kelvins today), and a consequent reduction in system temperature. Also, in the larger space available, the entire feed system can be cooled to 15 kelvins or below, thereby greatly reducing another source of thermal noise. These steps were assumed to be achieved in deriving the predicted performance curves for Ka-band presented earlier. Using Ka-band without these steps would surrender about 1.5 dB of the predicted performance. Updating the X-band system to the potential apparent in a beam waveguide design offers improvements on the order of 2 to 3 dB over current capabilities. The beam waveguide design also can be expected to improve the maintainability of the front-end equipment by virtue of the easier access and nontilting environment.

Taken together, this set of considerations forms a strong argument that any newly constructed antennas in the DSN should incorporate the beam waveguide design. This same set of considerations also applies to any major upgrade of the feed and microwave area of existing antennas, but the associated costs are a counteracting force and the decision process correspondingly less clear. The advantages of the beam waveguide configuration can be obtained for the current HEF antennas by modifying them as shown in Fig. 5.

The option set for the 70-meter antenna is more complicated because it carries a greater variety of services today. The current structure consists of a three-layer stack of cylindrical shells topped by three microwave cones whose mechanical structure is the same as that of the single cone on the smaller antennas. Equipment is mounted in all layers. Two of the three cones provide current S- and X-band services to spacecraft. The third cone provides host-country radio astronomy, the Goldstone Solar System Radar, and technology development support. Virtually all extant services must be preserved in any upgrade of this antenna. Installing Ka-band in one of the cones appears feasible, but with the likely performance penalty noted above, and there is still concern for available space. The space concern can be alleviated for the 70-meter

by replacing the selected cone with a one-third pie wedge occupying the same footprint on the supporting structure. Eventually all three cones would be replaced resulting in what has been termed the moncone configuration.

An intermediate option for the 70-meter has been termed the "hybrid" or partial beam waveguide. This option was conceived as a way to obtain the benefits of beam waveguide for Ka-band operation at a modest cost and without risk of degradation to services provided at S-band. For the hybrid option, the two cones providing current spacecraft support remain as they are, thereby retaining current performance levels needed for the Pioneers, the Voyagers, and Galileo. The third cone is removed and replaced with a mirror. The mirror directs the microwave beam into a bypass-style beam waveguide path to an alidade-mounted equipment room providing radio and radar astronomy functions and the new capabilities for Ka-band downlink and X-band uplink services to newer spacecraft. Retaining the cones and adding the beam waveguide requires that the focal length of the subreflector be retained as is, adding one more constraint to the design of the beam waveguide. Figure 6 illustrates one version of the hybrid beam waveguide concept.

IV. Ka-Band Technology and Environmental Effects

Many elements of the DSN and its surrounding environment affect 32-GHz (Ka-band) system performance much more than lower microwave frequencies now in use. Table 3 lists virtually all these elements, including the Earth's ionosphere, following a signal through the stratosphere and troposphere to its arrival at Earth and capture by the DSN. This table forms a menu for meditation, study, analysis, testing, and development to begin the process of getting the DSN ready for the support of missions using Ka-band. Many of these elements have been studied or are currently under study within the DSN Advanced Systems Program; details of the planned efforts can be found within the current Research and Technology Operating Plans (RTOPs).

Knowledge of antenna performance at Ka-band requires careful measurement at or near the actual operating frequencies. Achieving the desired level of performance is expected to require careful adjustment of the antennas as well. The program of holographic measurements to accurately adjust the antenna surface will therefore grow in importance.

On the 70-meter antenna at least, structural deformations due to gravity loading at differing elevation angles or due to wind loading could easily require active compensation to achieve full efficiency at Ka-band. For the purposes of plan-

ning, a seven-element array feed was assumed necessary and sufficient.

DSN antennas are used in a limited fashion at 22 GHz for radio astronomy; measurements at 22 GHz can help predict performance at 32 GHz. Measurements at the 44-GHz astronomy band could enable interpolation to refine our expectations for the 32-GHz behavior of the 70-meter antennas. A fully definitive answer, of course, will not be available until these antennas are instrumented at the 32-GHz Ka-band deep-space communications frequency. Preliminary microwave radiometry measurements should occur next year under currently proposed technology development activities. Installation of a fully capable Ka-band low-noise system is not now scheduled to occur prior to 1995.

A realistic test and demonstration of Ka-band deep-space performance comes with the Ka-band Link Experiment on Mars Observer (*KABLE*). A key element of this experiment is the simultaneous comparison of X-band with Ka-band signals emanating from a deep-space vehicle. DSN support to *KABLE* will be from the new advanced development antenna at DSS-13. On the spacecraft, *KABLE* is a simple quadrupler inserted parallel to the X-band path on the high-gain antenna (HGA). The resulting 33.6-GHz signal is out of the Ka-band space research band, but the low power density at Earth makes the experiment in conformance with radio regulations. However, the frequency is sufficiently close to the allocation for engineering measurements of link performance to be made. The quadrupler was the least costly spacecraft implementation option for the *KABLE* experiment. Implementation for committed mission support will induce more extensive changes to the flight hardware design.

Figure 7 shows the flight hardware elements necessary for utilization of Ka-band. Central to all is the deep-space transponder, which is only indirectly a Ka-band issue since a transponder is needed in any case. Certain performance requirements become more stringent if a Ka-band downlink is required, but irrespective of Ka-band, a new transponder must be developed for missions in the mid- to late 1990s. The transponder that Mars Observer procures may or may not be adequate for the new Ka-band-compatible transponder. The baseline deep-space transponder will have been designed for two-way X-band.

Two means of power amplification (Fig. 7) are considered options for Ka-band future application. The Ka-band solid-state array feed power amplifier (AFPA) depends on the development of new devices. The chief virtue of the AFPA is near lossless RF signal combining, because the RF signal combines directly at the focal point. Traveling-wave-tube amplifiers

(TWTAs) are needed for applications where DC power is particularly constrained, or where substantial RF power is required and radiation into antenna apertures can be achieved without excessive ohmic losses.

V. Implementation Scenario

Planning for major implementation for the DSN involves fitting the required activity into a time-constrained resource box. The beginning of the applicable time interval is defined by the availability of technology needed. The end of that interval is terminated by the delivery date for the required capability to support a mission. The box is further constrained by the limited out-of-service times allowed because of the need to support other missions which are already in flight. Figure 8 is an overview schedule showing the constraining and potentially driving missions and the target dates for the technology program, together with the favored Ka-band implementation scenario which is discussed in this article. This schedule defines a capability to meet the potential need dates of the missions currently in the preplanning stage. As the details of that future mission set evolve and solidify, the specifics of the Ka-band implementation scenario in the DSN will evolve to meet the agreed-upon needs of the customers' missions.

As a first step in the implementation, the DSN would equip a 34-meter subnet for cruise-mode support of CRAF/Cassini with X-band uplink/XKa-band downlink services by mid-1995. This capability would be available on at least two stations at CRAF launch and on the full subnet before Cassini launch. Support to the existing missions—Galileo, Magellan, Mars Observer, and others already in flight—limits the downtime windows available for network changes and constrains the options for installing Ka-band on existing subnets to those that can be accomplished with extremely brief downtimes. Specifically allowed would be replacement of the 34-meter standard (34-STD) subnet, or swapping the cone-module on the 34-meter high-efficiency (34-HEF) subnet. To meet the target schedule and distribute the effort over time, the construction funding should be embedded in the FY'91, FY'92, and FY'93 Construction of Facilities budgets, which will be defined during the 1988–1990 planning cycles.

The preferred configuration for the first 34-meter Ka-band subnet would be the replacement for the 34-STD subnet, using a center-fed beam waveguide antenna design derived from that of the new DSS-13 antenna. The basic antenna system would provide all services currently provided by the 34-STD subnet. To this would be added X-band uplink and then Ka-band downlink capabilities. Considering the space available in this type of structure, installation of Ka-band should be a simple

"drop-in" process, after the technology surprises have been met and conquered at DSS-13. The space and configuration also eases the way for future additions of Ku-band for critical Earth-orbiter support or C-band frequencies currently in use by the Soviet missions. This configuration, with its easy access and nontilting environment, should also reduce future maintenance efforts for the front-end equipment.

The second of the 34-meter subnets capable of X-/XKa-band services is potentially required by the end of 1999 to support the Mars Rover Sample Return (MRSR) mission during its high-activity phases. The configuration choice depends greatly upon the pathway chosen for the first of the 34-meter subnets. If the 34-STD subnet has been replaced and now supports X-band uplink operation, then downtime windows should exist to permit the 34-HEF subnet to be upgraded to a beam waveguide configuration. Only one of the six antennas capable of providing the critical X-/SX-band services would be out of service at any one time. If however, replacement of the 34-STD subnet had been deferred, then its replacement in the 1998-1999 time frame would be the only open option. Construction funding for the available option would be required in FY'97 and FY'98, which means that the decision time for the second 34-meter subnet is actually in the 1995-1996 planning cycle.

Establishing Ka-band on the 70-meter subnet presents its own set of special considerations. These antennas are the largest and most crucial elements of the DSN. Their performance at Ka-band can be the key to outstanding science return from Cassini during its Saturn satellite tour starting in 2003. Because of their very size, they are subject to added technology uncertainties in their pointing and in their structural deformation under gravity, thermal, and wind loading. These uncertainties are not present in the smaller 34-meter antennas. For that reason, it would be prudent to establish a quasi-operational best-efforts Ka-band capability on the Goldstone 70-meter antenna long before becoming committed to a specified level of Ka-band performance on the 70-meter subnet. The actual schedule driver for this capability is the MRSR mission approach to Mars, giving a DSN operational date in mid-1999. The Cassini mission is proposed to fly in 1996.

Installation and demonstration of the prototype 70-meter Ka-band capability at Goldstone prior to Cassini launch is desirable for two reasons. First, it offers a visible demonstration to the project of the intent to provide the Ka-band capability needed for its encounter. Second, it offers enough time for DSN personnel to discover and solve the special 70-meter Ka-band problems not present with the 34-meter, and to do that in time to avoid those problems with the operational configuration. Given current mission schedules, a downtime window will exist in 1994 which could be used to prepare

the antenna configuration as needed. This would require construction funding in FY'93, for which the critical decision point occurs in the 1991-1992 planning cycle.

The preferred configuration for this prototype 70-meter Ka-band installation was described earlier as the hybrid or partial beam waveguide. This configuration retains the cone configuration for the current S- and X-band services without noticeable degradation from their current performance. The added beam waveguide feature would provide for the demonstration of X-/XKa-band services, for research and development efforts of various sorts, and for radio and radar astronomy. If installed on the proposed schedule, the beam waveguide area would provide a place to install a supercooled X-band receive function, which could be demonstrated or used for best-efforts support of Galileo during its arrival at Jupiter. It also could provide a place to install the planned megawatt radar transmitter, without adding weight to the tipping structure of the antenna. Design of the partial beam waveguide would be constrained to facilitate a later upgrade to full beam waveguide when and if that became a correct step.

The full 70-meter subnet would be required to have X-band uplink and X- and Ka-band downlink services by mid-1999. The actual schedule driver as forecast today would be the MRSR approach to Mars, but Cassini's approach to Saturn is not long after this. For now, downtime windows appear to exist in the 1998-1999 time period to permit needed modifications and installation of Ka-band services. Construction funding would be required in FY'97 and FY'98, for which the critical decision time is the 1995-1996 planning cycle. There are three configuration options visible today for this installation, all of which should be well understood by decision time. These three options, all discussed in detail in the final report, are the full beam waveguide, the partial beam waveguide, or the expanded pie-wedge cone module. Experience with DSS-13 and a better understanding of the real mission drivers will facilitate that decision at the proper time.

VI. Conclusion

The conclusions of the Ka-band study effort can be briefly summarized. For a variety of reasons, Ka-band is the "right" next major step in deep-space communications. It offers increases in downlink telemetry capability on the order of 6 to 10 dB. It offers improved radio metric accuracy through reduced plasma sensitivity and increased bandwidth. And because of these improvements, it offers the opportunity to reduce costs in the flight radio system or in the DSN by allocating part of the overall benefit of Ka-band to this cost reduction. Improvement in DSN efficiency and productivity would thereby result from the introduction of Ka-band

operation. And the new capability would maintain and extend the visible NASA lead in deep-space communications.

As described in this article, a mission scenario is in planning which can drive at least two and possibly all three of the DSN subnets to provide a Ka-band downlink capability by the turn

of the century. In addition, the implementation scenario outlined here is feasible within reasonable resource expectations, and can provide the needed upgrade as a natural follow-on to the technology development which is already underway. The upcoming development on the new DSS-13 antenna forms a key part of that technology effort.

Acknowledgment

Although the specific form of this report is the result of the Ka-band study team's efforts, the technical foundation for it is a result of significant support by many members of the Telecommunications Division and the Office of Telecommunications and Data Acquisition. Their efforts are gratefully acknowledged.

References

- [1] "Ka-Band Capabilities" section, *TDA Progress Report 42-88*, vol. October-December 1986, Jet Propulsion Laboratory, Pasadena, California, pp. 96-172, February 15, 1987.
- [2] S. Dolinar, "A New Code for Galileo," *TDA Progress Report 42-93*, vol. January-March 1988, Jet Propulsion Laboratory, Pasadena, California, pp. 83-96, May 15, 1988.

Table 1. DSN frequency band requirements

Service	70-meter antenna	34-meter HEF antenna	34-meter standard and replacement	26-meter antenna
S/S	International Cometary Explorer Pioneer 6-8, 10, 11		AMPTE ^a Pioneer 6-8, 10, 11 ISTP-Wind et al. ^b	AMPTE ^a Earth-orbit launches Earth-orbit emergency Select earth orbit ISTP ^b
S/SX	Galileo Magellan Pioneer 12 Ulysses Voyager Venus Probe ^c Comet Sample Return ^d	Downlink: Pioneer Voyager Galileo	Galileo ISTP-Geotail ^b Magellan Ulysses Voyager Venus Probe ^c	(?) ISTP-Geotail ^b
C/L	Phobos			
C/C	Mars balloon Mars aeronomy Vesta, et al. ^e		Mars balloon (?) et al.	
X/SX	Comet Nucleus Sample Return (?) Galileo, Magellan	Comet Nucleus Sample Return Galileo, Magellan		
X/X	Mars Observer	Mars Observer	Lunar Geoscience Observer	Planetary launches (?) Lunar Geoscience Observer, Mars Observer
X/XKa	Comet Rendezvous Asteroid Flyby Mars Rover Sample Return MBAR, NEAR, SFSP ^f Comet Coma ^c	Mars Rover Sample Return	Mars Observer (demo) Comet Rendezvous Asteroid Flyby Mars Rover Sample Return MBAR, NEAR, SFSP ^f Comet Coma ^c	
X/SXKa	Cassini		Cassini	
Ku/Ku or X/Ku			Quasat Orbital transfer vehicle	Quasat (?) Space station (?)
Ka/XKa	Solar Probe			
Other	GSSR, Host R/A ^g		GSSR, SETI ^h	

^aActive Magnetospheric Particle Tracer Explorers.

^bInternational Solar Terrestrial Physics Programme. Wind is a NASA payload for ISTP. Geotail is a joint NASA-ISAS satellite.

^cInstitute of Space and Astronautical Science (ISAS), Japan.

^dISAS-European Space Agency (ESA).

^eUSSR-France.

^fMain Belt Asteroid Rendezvous, Near Earth Asteroid Rendezvous, Saturn Flyby-Saturn Probe.

^gGoldstone Solar System Radar, host-country radio astronomy.

^hSearch for Extraterrestrial Intelligence.

Table 2. Definitions of Ka-band options

Subnet	Services ^a	Configuration Options
34-meter standard (DSS-12 etc.)	S/SX ^b X/XKa (+S desired) C/C ^c Ku/Ku ^c	<ul style="list-style-type: none"> • Replace with center-fed beam waveguide antenna similar to new DSS-13 nucleus. • Replace with HEF-type antenna with multiband feedcone.
34-HEF subnet (DSS-15 etc.)	X/SX X/XKa	<ul style="list-style-type: none"> • Modify with multi-band feedcone. • Retrofit with bypass BWG and alidade feed room. • Rebuild for center-fed BWG into a feed room.
70-meter subnet	S/S S/SX X/SX X/XKa (+S desired) C/L ^c C/C ^c Host radio astronomy Radar astronomy (including megawatt)	<ul style="list-style-type: none"> • Tricone structure, modified as needed. • Monocone, possibly in 3 sectors. • Partial bypass BWG to carry new services in higher frequency bands, while leaving the S/S and S/SX high-performance elements in two legs of the current tricone. • Retrofit the existing antenna with a full bypass BWG providing all services. • Replace the existing antenna with a new 70-meter antenna similar in design to the Usuda-64.

^a Services available in 1988 will continue to be needed through the period of interest with essentially no change in performance quality (effective isotropic radiated power and gain/temperature). Added services vary by subnet.

^b Indicates concurrent uplinking at S-band and downlinking at S- and X-bands. Similar notation occurs throughout the table.

^c Separable option.

Table 3. Technological and environmental elements affecting or affected by Ka-band

Element	Impacts
Ionosphere	Radio metric delay and stability
Troposphere	Attenuation, noise temperature, weather
Antenna	Surface: Panel adjustment: static versus dynamic Holography assumed Pointing: Angle tracking and blind pointing Acquisition process
	Configuration Stability/deformation
Microwave	Configuration Bandwidth Stability LNA type Array feed: interaction with pointing
Receiver	Down-conversion/frequency span Phase-lock dynamics Stability Bandwidth Acquisition process Configuration: depends on microwave Coherent detection efficiency Doppler extractor: type and performance
Metrics	Bandwidth Doppler precision/stability Media effects Δ -DOR ^a and phase calibrations
Science usage	Primarily metrics
Telemetry rates	Customer-driven
Uplink	Stability (X/Ka multiplication) Rates/bandwidth: customer-driven
Predicts	Increased precision Responsiveness assumed fixed otherwise
Operations	Short pass/data dump option
Calibration beacon	Need a high-earth orbit spacecraft beacon

^aDelta-differential one-way range

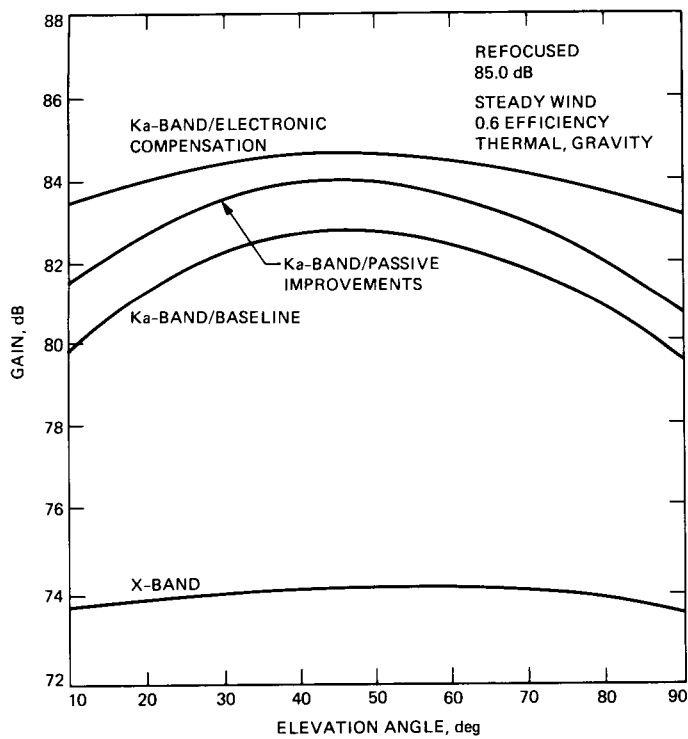


Fig. 1. 70-meter antenna performance at Ka-band.

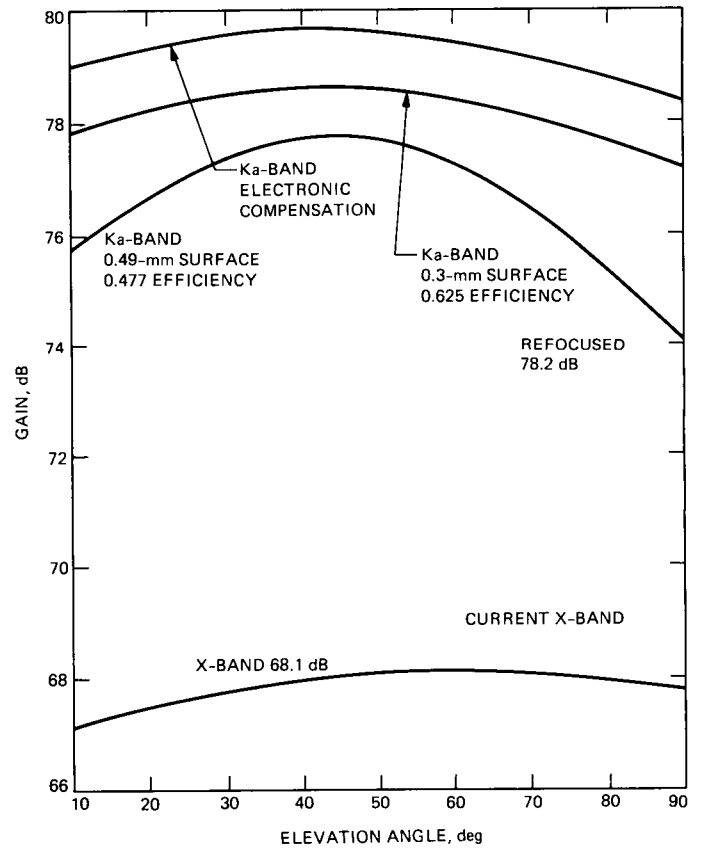


Fig. 2. 34-meter antenna performance at Ka-band.

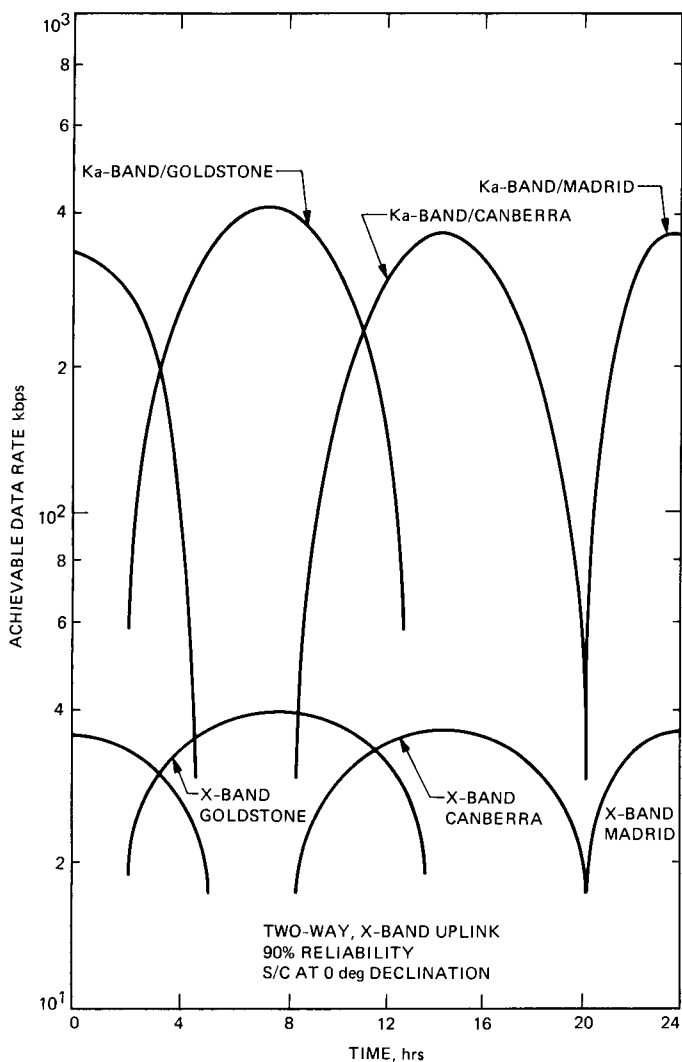


Fig. 3. Telecom performance advantage of Ka-band versus X-band.

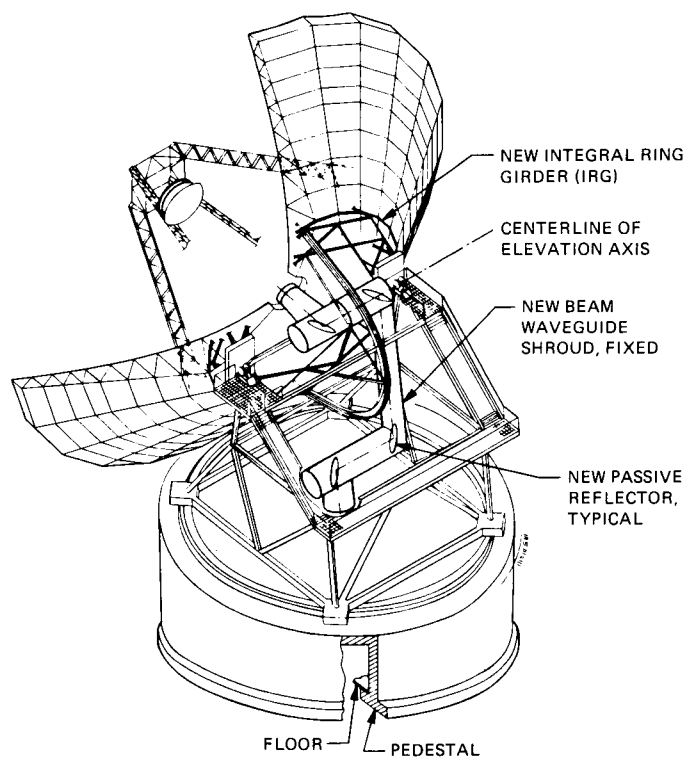


Fig. 4. Concept for new 34-meter replacement beam waveguide antenna.

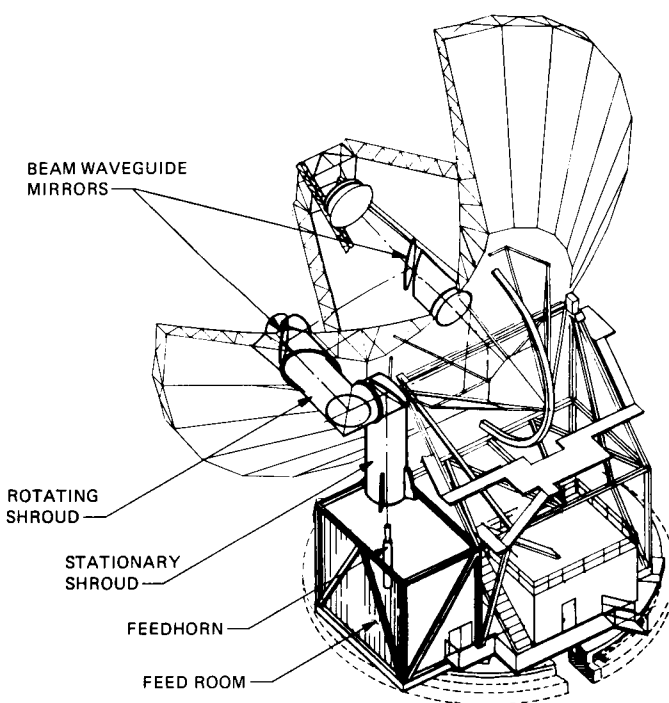


Fig. 5. Concept for modified 34-meter high-efficiency antenna with bypass beam waveguide.

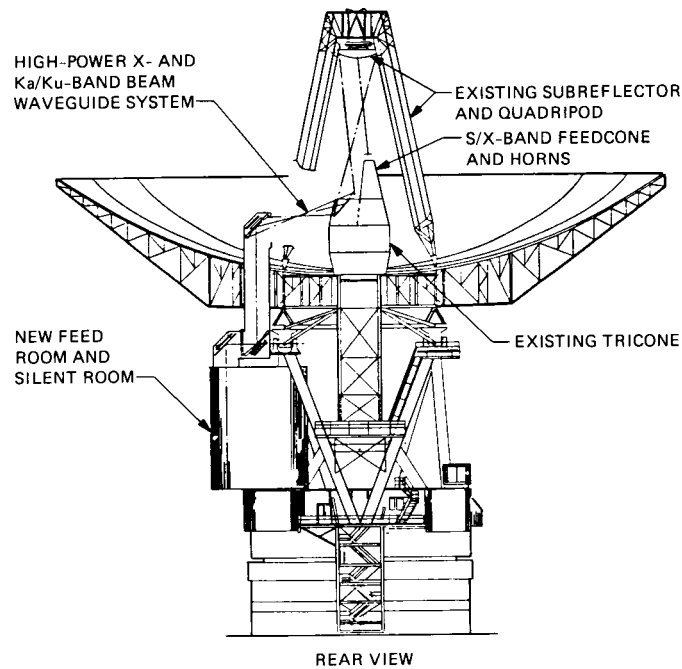


Fig. 6. Concept for 70-meter with hybrid beam waveguide.

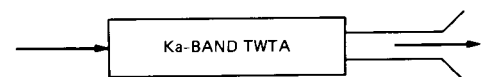
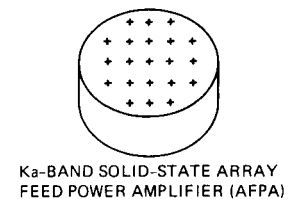
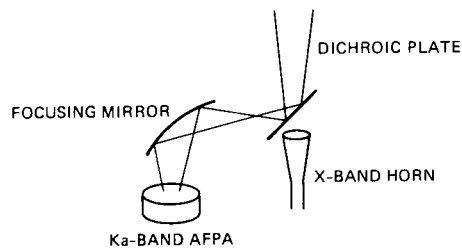
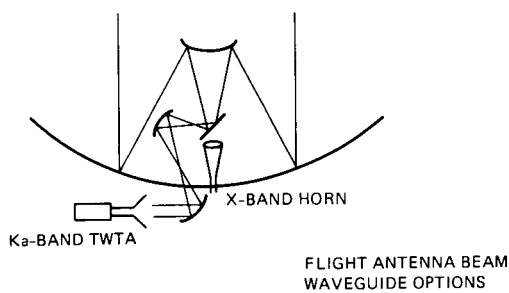
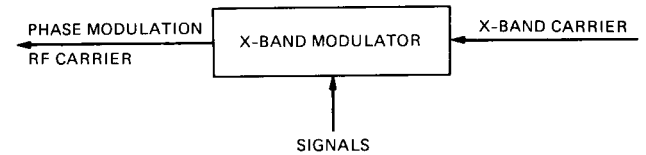
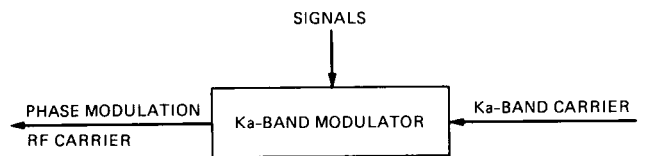
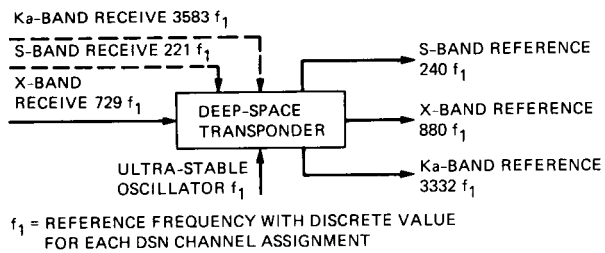


Fig. 7. Ka-band related spacecraft elements.

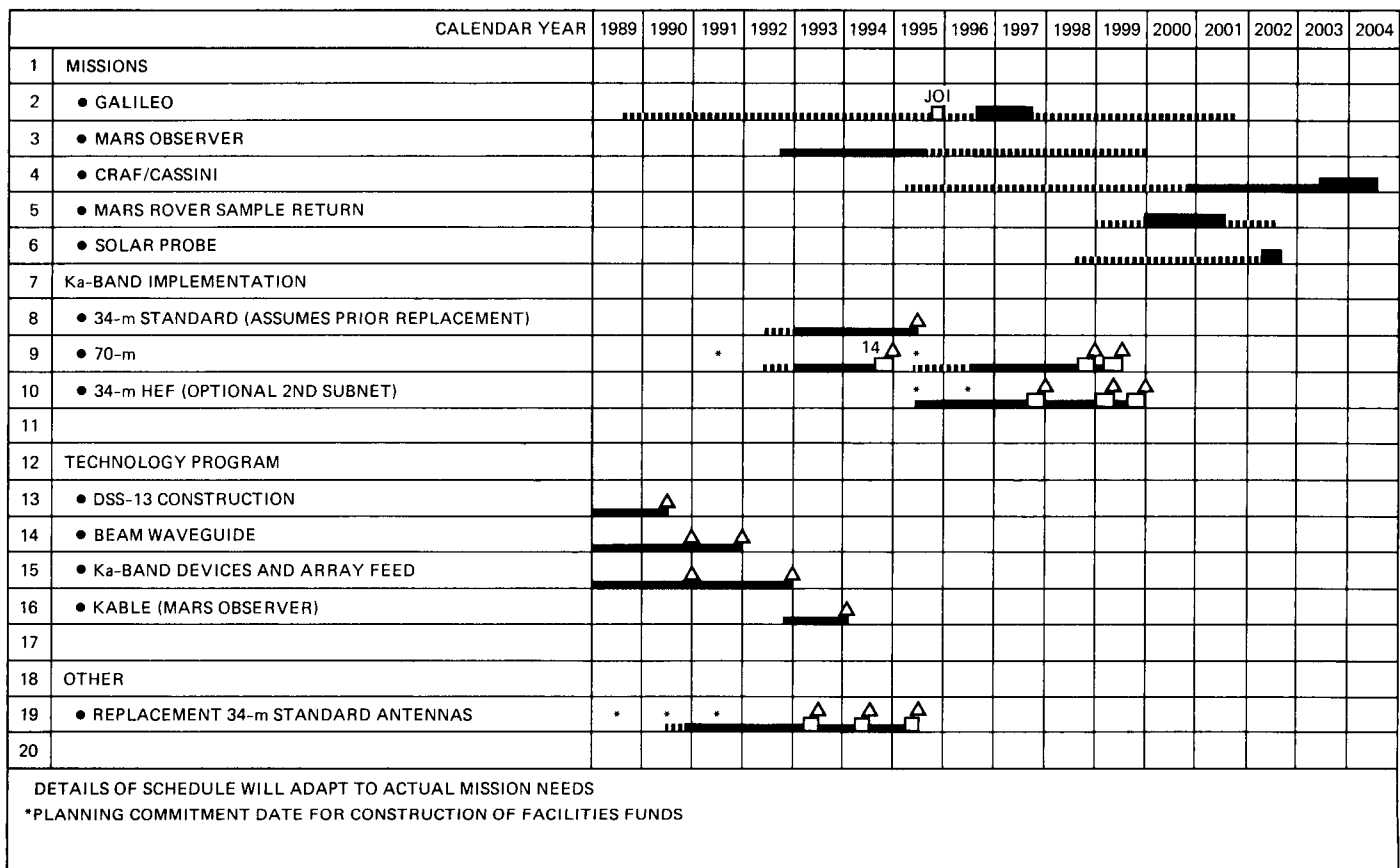


Fig. 8. Overview Ka-band schedule.